

****Volume Title****

*ASP Conference Series, Vol. **Volume Number***

****Author****

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An analysis of metallic high ion absorption line profiles at DA white dwarfs with circumstellar material

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Abstract.

Some hot DA stars exhibit circumstellar absorption in the metal resonance lines in their spectra. In many cases, these circumstellar features are unresolved from those originating in the photosphere. To better understand the effect this circumstellar blending has on photospheric abundance estimates, we present here an analysis of the unresolved metal high ion absorption features of six hot white dwarfs. In all cases, given the strong circumstellar C iv detections, the photospheric C iv abundances are reduced; conversely the weak circumstellar Si iv leads to modest photospheric abundance revisions. A possible new technique for modelling these line profiles is discussed, that can better reproduce the observations and provide a greater insight into the conditions of the circumstellar medium.

1. Introduction

The study of the circumstellar environment of white dwarf stars has proven to be of great interest in recent years. In addition to the circumstellar dust (e.g. Zuckerman et al. 2003) and gaseous discs (e.g. Gänsicke et al. 2006) seen at cooler white dwarfs due to tidally disrupted extra-solar minor planets and asteroids (e.g. Jura 2003), and the possible Kuiper belt type discs seen at hot white dwarfs with planetary nebulae (PNe; e.g. Su et al. 2007), circumstellar high ion absorption can be seen in the ultraviolet spectra of some hot DAs, thought to originate in either interstellar medium (ISM) or ancient, diffuse planetary nebula remnants near enough to the hot stars to be ionised (Bannister et al. 2003; Dickinson et al. 2012b). In many cases, the velocity of the circumstellar material is sufficiently close to the photospheric velocity for the absorption lines to be unresolved, resulting in asymmetric, blended line profiles. Several previous studies of photospheric metal abundances (e.g. Barstow et al. 2003) fit these blended line profiles with only photospheric models, possibly leading to over-estimates of stellar metal abundance. Indeed, the study of Dickinson et al. (2012b) found that the circumstellar C iv near G191-B2B accounts for 128.77 of the 160.01 mÅ equivalent width of the 1548 Å absorption feature; similarly, the equivalent width of the circumstellar component of the 1550 Å line (with a total equivalent width of 141.93 mÅ) is 106.47 mÅ.

Some DA stars have metal abundances in excess of those seen in white dwarf stars with similar effective temperature (T_{eff}) and $\log g$ values. While accretion from circumstellar material may be enriching the photospheres of some of these degener-

ates (such as GD 394), it may also be the case that in some of the stars circumstellar absorption at a velocity indistinguishable from the photospheric velocity may be contributing to the equivalent widths of the absorption features, giving the impression of higher metal abundances.

Following this, inconsistencies in abundances derived using different ionisation stages may also be due to the contamination of the line profiles of resonance lines. The C abundance of G191-B2B derived by Barstow et al. (2003) using the C iv resonance doublet, without accounting for the circumstellar contamination ($C/H = 4.00 \times 10^{-7}$), is just over double that derived using the C iii features ($C/H = 1.99 \times 10^{-7}$). Furthermore, using the C abundance derived from the C iv doublets in the spectra of WD 1942+499 and WD 2257-073, Lallement et al. (2011) predicted a strong C iii multiplet that was not observed, leading to the conclusion that the observed C iv was circumstellar.

Given the importance a robust understanding of photospheric composition has when deriving accurate stellar parameters, and the use abundance inconsistencies may have as a diagnostic of the presence of circumstellar material, the effect of accounting for the circumstellar absorption on photospheric abundance is explored here.

2. Method and Observations

Of the 23 objects studied by Dickinson et al. (2012b), eight displayed unambiguous circumstellar material, and at only two objects (REJ 0457-281 and REJ 1738+665) was the absorption from this material completely resolved from the photospheric absorption lines, while the circumstellar material at Feige 24 was resolved at only one binary phase. The remaining six objects (including Feige 24) with blended absorption features, their stellar parameters and observation information, are given in table 1. The *Hubble Space Telescope* Space Telescope Imaging Spectrograph (STIS) and Goddard High Resolution Spectrometer (GHRS) spectra were fit using XSPEC (Arnaud 1996), and the circumstellar components (to C iv at all stars, and Si iv at REJ 1614-085, WD 2218+706 and Ton 021) were modelled using the Gaussian absorption line model ‘GABS,’ provided with initial parameters calculated using the circumstellar line properties (circumstellar velocity, b value and column density) measured by Dickinson et al. (2012b). The photospheric components were modelled using TLUSTY (Hubeny & Lanz 1995), and were placed at the photospheric velocity found by Dickinson et al. (2012b). Absorption lines from all elements other than that considered in each spectral region (1545 to 1555 Å for C iv and 1390 to 1405 Å for Si iv) were excluded from the fit to avoid the coupling of abundances across chemical species. However, the other photospheric metals examined by Barstow et al. (2003) were included in the ‘background’ of the models at the abundances found therein. All parameters were allowed to fit freely, except for stellar T_{eff} and $\log g$, which were constrained to the error range stated in table 1. The two spectra of Feige 24 were fit separately, not co-added as in previous work, to allow a consistency check of the abundances derived with and without the circumstellar contamination. 1σ errors were computed on all abundance estimates.

3. Results

The abundances measured here are presented in table 2. The introduction of circumstellar components to the fits reduces the measured C iv abundances of the stars when

Table 1. The objects studied, ordered by T_{eff} , their stellar parameters (from Barstow et al. 2003) and the observation information for the data used.

WD	T_{eff}	$\log g$	Data Source	Resolving Power
Ton 021	69 711 \pm 530 K	7.47 \pm 0.05	<i>STIS</i> [E140M]	40 000
Feige 24 [†]	60 487 \pm 1 100 K	7.50 \pm 0.06	<i>STIS</i> [E140M]	40 000
REJ 0558–373	59 508 \pm 2 200 K	7.70 \pm 0.09	<i>STIS</i> [E140M]	40 000
WD 2218+706	58 582 \pm 3 600 K	7.05 \pm 0.12	<i>STIS</i> [E140M]	40 000
G191-B2B	52 500 \pm 900 K	7.53 \pm 0.09	<i>STIS</i> [E140H]	110 000
REJ 1614–085	38 840 \pm 480 K	7.92 \pm 0.07	<i>GHRS</i> [G160M]	22 000

compared to the previous study of Barstow et al. (2003) (figure 1). The weaker circumstellar Si IV makes a small difference to the measured photospheric abundance (figure 2). However, it must be noted that the combined effect of modelling the circumstellar components with a simple Gaussian profile, not a physically robust line profile prediction, and the increased degrees of freedom to the model, make the statistical errors on the fits large in some cases. The new C abundances for Feige 24 agree across both data sets. The improvement achieved progressing from a line profile model with only a photospheric component (figure 3), to one containing both photospheric and circumstellar absorbers is shown in figure 4.

Table 2. The abundances measured in this study, with 1σ uncertainties.

WD	C IV/H [$\times 10^{-7}$]	+1 σ [$\times 10^{-7}$]	–1 σ [$\times 10^{-7}$]	Si IV/H [$\times 10^{-7}$]	+1 σ [$\times 10^{-7}$]	–1 σ [$\times 10^{-7}$]
Ton 021	0.43	0.40	0.14	29.6	7.67	8.37
Feige 24 [†]	1.62	0.88	0.55			
Feige 24 [‡]	1.69	1.83	0.66			
REJ 0558–373	0.41	4.87	0.15			
WD 2218+706	4.08	4.96	2.23	5.08	17.4	2.33
G191-B2B	1.40	0.21	0.21			
REJ 1614–085	4.00	1.44	2.94	0.07	0.08	0.05

[†]resolved spectrum (0.74 binary phase), [‡]blended spectrum (0.24 binary phase).

4. Conclusions

The significant effect of circumstellar contamination to photospheric abundance measurements, based on resonance line profile models, is evidenced by the change in abundances shown here. Indeed, when accounting for the circumstellar component in the C IV doublet in the spectrum of G191-B2B, the C abundance derived is in keeping with that found using the C III features by Barstow et al. (2003) and with that found using *FUSE* data (Barstow et al., these proceedings). Coupled with the use of inconsistencies in abundances derived from different ionisation stages by Lallement et al. (2011), this study demonstrates the validity of using unusual photospheric abundance measure-

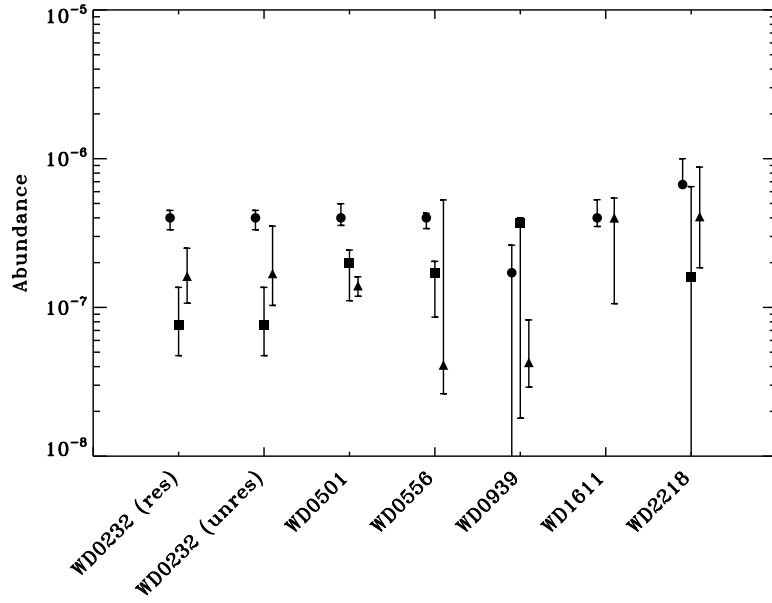


Figure 1. The C abundances measured in this study using the C IV doublet (triangles), compared to the abundances derived using the C III (squares) and C IV (circles) absorption features by Barstow et al. (2003).

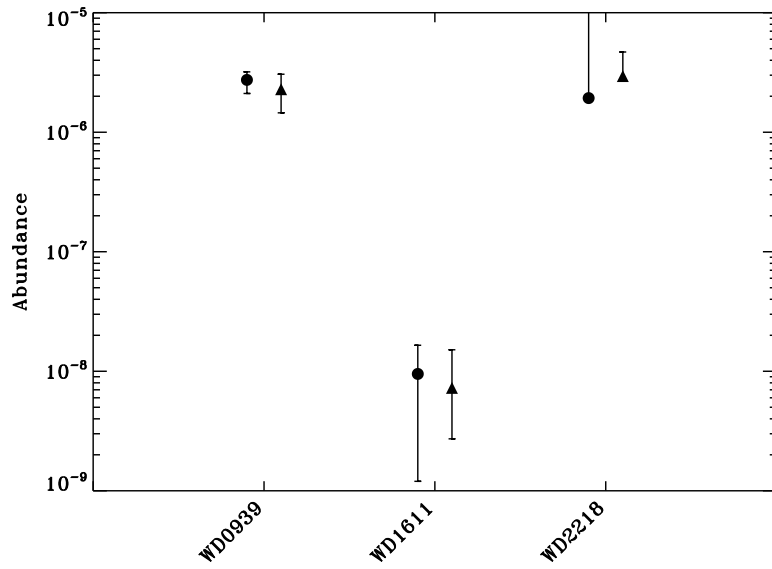


Figure 2. The Si abundances measured in this study (triangles), compared to the abundances derived by Barstow et al. (2003) (circles).

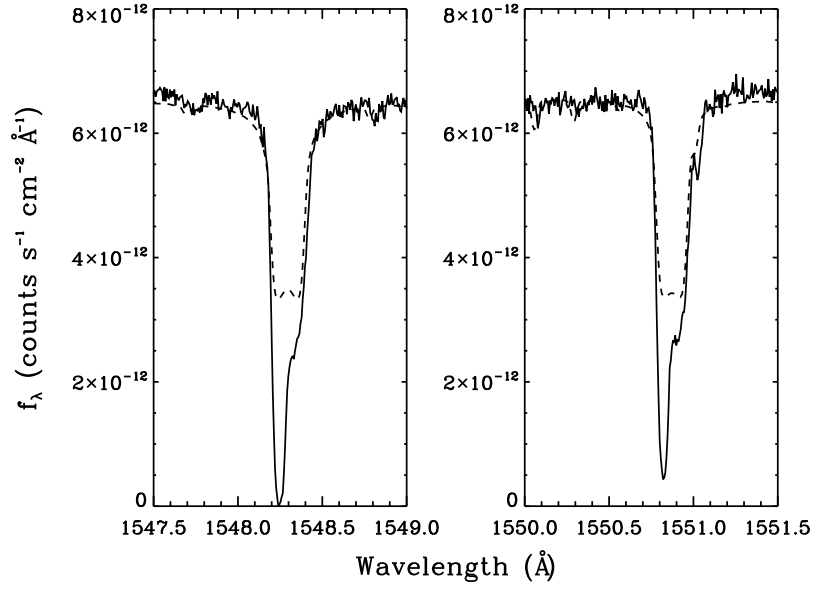


Figure 3. The C iv doublet of G191-B2B, fit with a model spectrum with the C abundance ($C/H = 4.00 \times 10^{-7}$) derived from the C iv doublet by Barstow et al. (2003). The observed data is shown with a solid line, while the model is plotted with a dashed line.

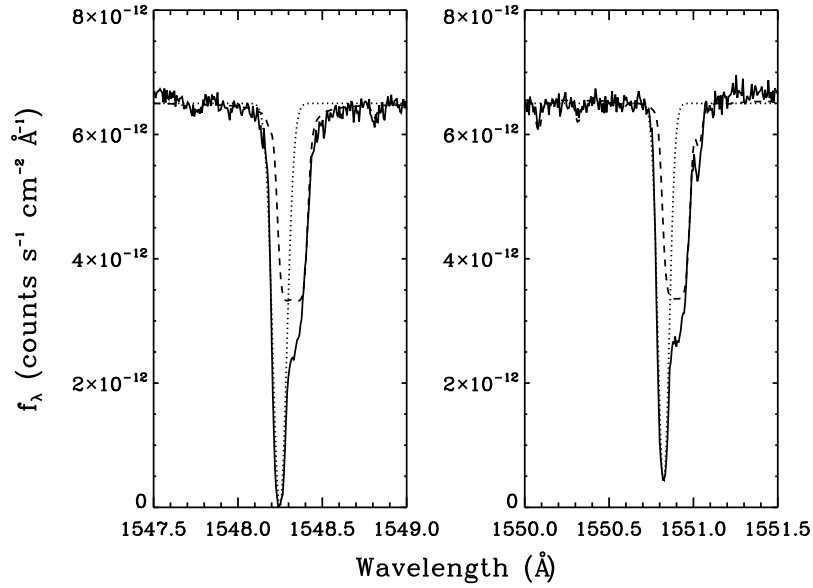


Figure 4. The best fitting model of the C iv doublet of G191-B2B, with a photospheric C abundance of 1.4×10^{-7} relative to hydrogen (dashed line). The dotted line represents the circumstellar component and the solid line is the observed spectrum.

ments as a diagnostic of the presence of circumstellar material in the absorption line profile. This will be particularly useful in cases where circumstellar material is completely unresolved from that in the photosphere, and symmetric line profiles are present.

The C abundance seen at REJ 1614–085 here is larger than that of any other DA of similar T_{eff} (Barstow et al. 2003), and is inconsistent with the abundance derived from this star’s *FUSE* data (Barstow et al., these proceedings). Coupled with the difficulties in ascertaining the distribution of photospheric nitrogen (Dickinson, Barstow, & Hubeny 2012a) and the presence of Si in this star at an abundance comparable to cooler DAs that are likely to be accreting (Barstow et al. 2003, Dupuis, Chayer, & Henault-Brunet 2010), it may be that this star is accreting from an as yet undetected source (Burleigh et al. 2010, 2011).

However, the larger errors on some of the measurements in this study are far from ideal. One way in which this may be minimised is to use physically robust, model line profiles for both the photospheric and circumstellar components, providing a greater insight into the conditions of the circumstellar medium beyond the measurement of b values and column densities. Indeed, the comparison of line profiles from different physical models to those observed may provide a powerful technique in ascertaining the source of the circumstellar material seen in the spectra of these hot DAs.

Acknowledgments. N.J.D. and M.A.B. acknowledge the support of STFC. B.Y.W. would like to acknowledge Guaranteed Time Observer funding for this research through NASA Goddard Space Flight Center grant 005118. N.J.D. wishes to thank Jay Holberg and Ivan Hubeny for useful discussions.

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